5. ANNUAL AVERAGE MEASUREMENT PROGRAM

The annual average measurement program provided information to understand the causes of $PM_{2.5}$ annual averages that might exceed the 15 $\mu g/m^3$ limit. This section specifies the variables measured, averaging times, sampling and analysis frequencies, monitoring systems, and sampling sites that were installed and operated by CRPAQS for the long-term annual average study. It also describes how CRPAQS measurements and those assembled from other networks will be used to address each of the study objectives specified in Section 1.

5.1 CRPAQS Annual Average Aerosol Measurements

Table 5.1-1 specifies the particle and precursor gas measurements that were taken as part of CRPAQS for the December 1999 through January 2001 long-term monitoring period. This table presents information that was introduced in Section 4, but summarizes it to show which measurements were located at which sites during the annual program. The measurement code letter designations are those that were listed in Table 4.4-8. These measurements complemented and supplemented those acquired as part of the ARB backbone network. Taken together, they constitute a large coverage of background, interbasin transport, intrabasin gradient, source-oriented, and community exposure sites.

The entire network included the application of advanced, middle, and simple technologies for particle measurements. Advanced continuous and filter-based measurements were applied at the anchor sites. These sites required a large and expensive infrastructure in terms of hardware, software, technician training, space, power and security. The urban anchor sites in Bakersfield and Fresno were community-representative CORE sites that were shown in Section 2 to be most likely to exceed the annual and 24-hour $PM_{2.5}$ NAAQS.

Middle technology measurements were implemented by the ARB backbone $PM_{2.5}$ network using a combination of EPA Federal Reference Method (FRM) filter samplers, EPA speciation samplers, Federal Equivalent Method (FEM) sequential filter and IMPROVE samplers, and Correlated Acceptable Continuous (CAC) monitors. As shown in Section 4, this network is extensive in sampling frequency and spatial representation. Fixed sites supporting these measurements require substantial support infrastructure, but this was provided by the ARB and central California air quality districts with minimal supplemental support provided by CRPAQS. The measurement technologies applied in the backbone network are well established, but they were heretofore only applied in research networks.

Simple technology measurements applied Minivol filter samplers collocated with low-cost nephelometers to acquire information between the backbone and anchor network sites. These stations required little physical infrastructure beyond the sampling equipment, and were relatively inexpensive to implement. Extra Minivol samplers with quartz filters were located at some of the anchor, backbone, and satellite sites to obtain groups of samples that were extracted together from each site to obtain a representative organic speciation for annual average source apportionment.

Annual average aerosol samples were analyzed for mass concentration, elements (Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Tl, Pb, and U), water-soluble ions (chloride, sulfate, nitrate, ammonium, sodium, and potassium), and carbon (organic and elemental carbon). CRPAQS aerosol chemical measurements are compatible with and comparable to those acquired from the speciation monitors operated at backbone sites identified in Section 4. All of the sixth-day satellite site samples with 24-hour filter sampling were analyzed for the entire 14-month annual average period, as were samples from sequential filter samplers at the anchor sites on the same sixth-day schedule. The particulate organic samples collected on Teflon-impregnated glass fiber filters were aggregated for the year 2000 at each site for extraction and analysis of an entire year's worth of samples.

Some samples collected at the anchor sites between the sixth day sampling schedule may be selected for elemental analysis, based on elevated concentrations observed at some sites. These will most probably be days that correspond to nearby source or windblown dust events. These samples, if and when they are selected, will be submitted to full chemical analysis to examine episodes that might develop outside the winter intensive measurement campaign.

5.2 CRPAQS Annual Average Meteorological Measurements

Table 5.2-1 summarizes the meteorological instrumentation located at key sites in the CRPAQS annual network. The surface meteorological sites emphasized measurements at anchor sites, where high quality temperature and relative humidity are needed to apply chemical equilibrium models, at interbasin transport sites to determine flows and particle fluxes (estimated by nephelometer/particle measurements), and at several of the upper air measurement sites to correspond with the elevated meteorological measurements.

The upper air measurements were acquired with radar profiler, RASS, sodar/mini-sodar, and rawinsonde systems for the long-term study. Profilers and RASS required substantial support infrastructure and were located according to strict siting requirements with respect to nearby obstructions that interfere with the signals and residents who are annoyed by the high-pitched noise. The rawinsonde launches were the normal twice per day (0400 and 1600 PST) measurements acquired at military bases and by the National Weather Service.

Table 5.2-1 also identifies the instrumentation located on the 100 m tower at Angiola, and on a 20 meter tower operated by NOAA on an adjacent plot of land.. These towers acquired high time resolution measurements of meteorology at several levels and represent a key element in the interpretation of boundary layer evolution. The towers were operated throughout the year to provide a database that can be examined under a variety of climatological conditions.

5.3 Special Studies

Three preparatory and one summer study were conducted as part of the long-term measurement program. The three preparatory studies were: 1) measurement evaluation study; 2) Sierra Foothills site evaluation study; and 3) winter forecast accuracy study. The summer 2000 study was a detailed particle organic characterization study as well as a study of atmospheric transport from the SJV and the Los Angeles Basin into the Mojave Desert.

5.3.1 Measurement Evaluation Study

The objectives of the measurement evaluation study were to: 1) evaluate the practicality and durability of new monitoring instruments under central California winter conditions, especially continuous monitors; 2) develop data acquisition and reduction procedures for these measurements; 3) determine the equivalence and predictability among different measurement methods, and 4) evaluate the extent to which the expected pulse-widths of high-time resolution instruments assists in the interpretation and modeling of integrated aerosol samples. Method development was explicitly excluded as an objective for this study owing to resource limitations. Only instruments that existed and had proven their operability elsewhere were part of this evaluation.

The measurement evaluation study was conducted at the Bakersfield-California site during December 1998 and January 1999. This site has been used for several comparison studies (e.g. Pitchford et al., 1997). The measurement evaluation study was conducted jointly by CRPAQS and by the ARB Monitoring and Laboratory Divison as part of their assessment of instruments to be included in their long-term statewide network. Table 5.3-1 identifies the instruments that were evaluated. All of the instruments were located within the ARB facility in Bakersfield or on the roof of the building, as appropriate.

Collocated measurements were conducted throughout the comparison study. Filter-based samplers were compared with one another as well as with continuous analyzer measurements, which could be averaged over the same period as the filter-based samplers. Full details of the Bakersfield instrument comparison and its findings can be found in the final report for the comparison study (Dutcher, et al., 1999).

Several of the findings from the Bakersfield instrument comparison influenced the selection of instruments to be used in the CRPAQS annual and seasonal studies:

- The new continuous sampling methods for particulate nitrate and organics performed well and showed promise for inclusion in the network.
- The Minivol particulate sampler, the core of the CRPAQS satellite network, performed well, as expected.

- The UC Riverside aerosol time-of-flight mass spectrometer (ATOFMS) provided reliable and interesting single-particle data. The ATOFMS was subsequently used at Angiola and Fresno during the winter 2000-2001 intensive period.

- The continuous ammonia sampler did not meet expectations for reliability or detection limit. It was not incorporated into the CRPAQS network.

- The baseline of the DUSTTRAK photometer was found to vary significantly as a function of temperature when operated under ambient conditions. This same effect was observed as part of the Sierra Foothills Elevation Study, described below. Consequently, the DUSTTRAK photometer was not used in CRPAQS, and an integrating nephelometer was selected instead. Additional information regarding the pre-study testing of the nephelometer is presented in Section 9.

5.3.2 Winter Forecast Accuracy Study

The forecast accuracy study is being conducted during the winters of 1998-99 and 1999-2000. The objective of this study is to develop, apply, refine, and evaluate a wintertime forecast protocol that allows the meteorological conditions conducive to high wintertime $PM_{2.5}$ episodes to be predicted. A similar study was conducted prior to SCOS-97 and episode forecasting was substantially improved. As explained in Sections 2 and 3, persistent Great Basin high pressure systems with at least four days persistence between Pacific storm fronts usually result in the prolonged periods of low ventilation during which $PM_{2.5}$ levels increase and are sustained.

5.3.3 Sierra Foothills Elevation Study

The purpose of this study during winter 1998-1999 was to evaluate several candidate sites in the Sierra Foothills east of Fresno/Visalia to determine the extent to which they are within or outside of the valleywide mixed layer during winter. The objective was to identify a location for a winter anchor site that would be near the top of the valleywide mixed layer, sometimes falling within the layer and sometimes above it. Sites that were evaluated were:

- **Hurley/Marshall Station (375 m asl, N 37° 00' 50", W 119° 34' 11"):** This site at the California Department of Forestry's Hurley fire station was in a small valley with open exposure to the SJV, to the south.

- **Trimmer (510 m asl, N 36° 55' 14", W 119° 18' 18"):** This site was ~15 km south of the other sites, near Pine Flat Lake. The USFS heliport has good exposure to the valley (to the south), and helped to evaluate any lateral differences in the valley airmass, as compared to Prather.

- **Prather (515 m asl, N 37° 02' 09", W 119° 30' 42"):** This site in the town of Prather was at the USFS ranger station. Haze in the SJV could be seen beyond a wooded ridge from this site.

- **Millerton Lake (180 m asl, N 36° 59' 13", W 119° 41' 10"):** This site was on the south side of Millerton Lake, near Friant Dam. It was near a campground entrance road and the State Park headquarters building. To the southwest is a valley just over the small ridge. This site was selected because it was expected to be within the valleywide layer most of the time.

- **Mountain Rest (1250 m asl, N 37° 03' 13", W 119° 22' 20"):** This site was at a USFS ranger station that was expected to be above the valleywide layer. Although the valley is not clearly visible from the USFS building, the area is exposed to the valley and views can found from nearby ridges.

DUSTTRAK photometers with 5-min averaging times were operated at each of these sites from December 1998 through February 1999. Their measurements were examined to determine when they were in clear air and when they detected elevated particle concentrations or fog. Short-term spikes reveal the extent to which local, rather than regional-scale, particles reach each site.

The low-elevation Millerton Lake site was found to be within the fog or haze much of the time, even when the other sites exhibited clear air. Conversely, the Mountain Rest site was in clear air most of the time, even when there was haze in the valley and at the other sites. The Mountain Rest site exhibited a number of spikes in light scattering, but these short-term events were attributed to local woodburning.

The three mid-elevation sites (Hurley/Marshall Station, Trimmer, and Prather) exhibited behavior that indicated they were near the top of the haze layer. During some multi-day episodes their values would track those at Millerton Lake, indicating that they were within the haze layer. At other times, these three sites exhibited clear air when there was haze in the valley. Hence, a candidate elevation range of around 400 to 600 m was chosen for the Sierra Nevada Foothills site. The actual site chosen for the annual study, located between Prather and Auberry, was at 589 m.

5.3.4 Summer Study

A summer organic aerosol composition study was conducted at the Fresno First Street site during July and August 2000. The objectives of this study were: 1) determine detailed source contributions to 24-hour summertime organic carbon in the urban area; and 2) contrast compositions and source contributions with wintertime measurements at the same location. 24-hour filter/PUF/XAD samples were taken on the sixth day schedule and submitted to detailed analyses for the types of organic compounds identified in Section 2. This special study supplemented detailed organic speciation obtained from the annual analyses to be obtained from filter composites.

A second component of the summer 2000 special studies addressed long-range transport of visibility-reducing airmasses into the Mojave Desert. The measurement aspects of the summer long-range transport study were:

- **Anchor site at Edwards Air Force Base:** An anchor site oriented toward components of light extinction was operated in the Mojave desert during the summer to evaluate the timing and intensity of light extinction and the aerosol components that cause it. A 7-wavelength aethalometer and two beta attenuation monitors ($PM_{2.5}$ and PM_{10}) operated throughout the summer months, from late June through early Septembet, 2000.

- **Satellite transport sites from South Coast Air Basin and the SJV:** Satellite sites using portable nephelometers were located along transport pathways during the summer period to determine the magnitude, direction, and duration of visibility-reducing atmospheric constituents along pathways from the Los Angeles area for comparison with measurements of these constituents moving from the San Joaquin Valley into the desert. New summer sites at Bouquet Canyon, Cajon Pass, Cantil, Soledad Canyon, and Walker Pass were established for this study. Nephelometer data from the annual sites at Barstow, China Lake, Edwards, and Tehachapi Pass were also used in the analysis.

5.4 Uses of Annual Study Measurements to Attain Objectives

The following sub-sections briefly describe how the measurements described for the long-term study will be used to accomplish each of the CRPAQS field study objectives specified in Section 1. Separate CRPAQS modeling and data analysis plans pose questions similar to those of Section 3 and describe the activities that will be completed to answer these questions using CRPAQS field study data.

5.4.1 Annual Study Objective 1: Quality Data Base

Performance tests, quality audits, and measurement comparisons will be used to evaluate the accuracy, precision, validity, and completeness of the CRPAQS database. This evaluation will be especially important for the continuous aerosol measurement methods that are likely to be incorporated into the backbone network for long-term monitoring. Section 3 described how tests to date show that some of these instruments provide $PM_{2.5}$ measurements that are reasonably equivalent under some aerosol composition and meteorological conditions, but that are widely divergent under other conditions. The existing meteorological network also has limitations that can only be quantified via comparisons with the more accurate and precise measurement methods deployed as part of CRPAQS.

In particular, comparisons will be made among light scattering and light absorption continuous methods and filter-based measurements for different humidities, temperatures, monitor locations, chemical compositions, and concentration levels. Cases of large disagreement between collocated measurements will be examined in detail to identify the special circumstances that cause that disagreement.

These evaluations, supplemented by periodic performance tests and quality audits, will result in data qualification statements for each measurement network, measurement device, and specific sub-sets of measurements that will be integral parts of the CRPAQS data base. These statements will guide further analyses that use these data and provide quantitative uncertainty estimates that should be propagated through those analyses.

5.4.2 Annual Study Objective 2: Evaluate Backbone Network

The backbone network will determine which Metropolitan Planning Areas (MPA) are in compliance with the annual $PM_{2.5}$ NAAQS of 15 μg/m^3. This determination may or may not involve spatial averaging in Community Monitoring Zones (CMZ) that include multiple samplers, such as those in Fresno, Bakersfield, and other large cities. The combination of high time resolution measurements at anchor sites with the supplemental spatial resolution of satellite sites allows quantification of the degree to which these fixed locations represent concentrations in other areas.

Five and ten minute average concentrations at anchor and selected satellite sites will be examined for short pulses of $PM_{2.5}$ that can be attributed to nearby intermittent emissions or to small and short-duration changes in wind direction. These pulses will be separated from the more smoothly varying diurnal changes in $PM_{2.5}$ concentrations and integrated to estimate neighborhood-scale contributions with respect to urban-scale and regional-scale contributions. Urban contributions will be separated from regional contributions by comparison of time series from urban sites with those at interbasin gradient and background sites.

The spatial variability of $PM_{2.5}$ concentrations will also be evaluated for $PM_{2.5}$ and specific chemical components for different meteorological and emissions situations. Backbone network sites that show large deviations from nearby satellite monitors will be identified and the causes of the discrepancies will be sought. Redundancy among measurements from backbone monitors within a CMZ will also be determined. These data and their analyses will indicate how the ARB $PM_{2.5}$ network can be optimized with respect to location and frequency for compliance determination.

5.4.3 Annual Study Objective 3: Temporal and Spatial Distributions

Aerosol measurements will be examined to determine diurnal, weekly, and seasonal variability with respect to mass and chemical composition. These patterns will be interpreted in terms of changes in meteorology, proximity to or distance from emissions sources, variability within and between modeling grid squares, and representation of community exposure.

5.4.4 Annual Study Objective 4: Boundary Layer and Regional Circulation

Horizontal winds from profilers and surface stations at various elevations above ground level will be examined for different times of the day, week, season and year. Large-scale flows will be related to different synoptic conditions and variations will be identified. In particular, the extent to which the permanent meteorological network represents, or does not represent, interbasin and intrabasin transport will be determined. Common transport directions and transport duration will be determined for each layer and related to simple indicators, such as Oakland/Las Vegas pressure gradients, where possible.

Large-scale features of boundary layer evolution will be determined from RASS data, with special attention given to how surface and valleywide layers change for different synoptic conditions, different times of the year, and different central California locations.

Small-scale features of boundary layer evolution will be determined from the 100 m tower measurements. The timing and extent of vertical mixing between the surface layer and the valleywide layer will be determined. Upward movement of particles owing to heat buoyancy and turbulence will be balanced against downward movements owing to heat and momentum transfer as well as gravitational settling. Dispersion under low wind speed conditions will be elucidated for better customization of dispersion models.

The frequency, duration, spatial extent, and intensity of meteorological variables that affect pollution will be compiled by season to create a pollution climatology. This will include: 1) temperatures and relative humidities that affect ammonium nitrate equilibrium; 2) insolation that affects photochemical transformations; 3) precipitation that facilitates particle removal; 4) above threshold wind velocities that might suspend dust; and 5) fogs and low clouds that might enhance secondary aerosol formation.

Meteorological models will be applied to the profiler, RASS, and tower measurements. These measurements will also be used to evaluate the accuracy and validity of the model formulations.

5.4.5 Annual Study Objective 5: Source Zones of Influence and Contributions

$PM_{2.5}$ chemical measurements will be used with the CMB model to estimate primary source contributions to ambient concentrations for individual samples and annual averages. The annual average organic compound measurements will determine subsets of contributions to organic carbon, including diesel, cold start, high emitter, and hot stabilized vehicle exhaust contributions. Contributions from field burning, residential heating, cooking, and other organic carbon sources will be sought.

Outputs from the wind models will be used in transport and transformation models to determine which source areas or specific sources could have made negligible, minor, moderate, large, or major contributions at each receptor. Source contribution estimates at different locations will be compared to determine their consistency with emissions inventories and modeled zones of influence.

5.4.6 Annual Study Objective 6: Secondary Aerosol Sources

This objective will not be extensively studied as part of the long-term study. It is a major focus of the winter and fall studies.

For the long-term annual average study chemical transformation mechanisms will be included in air quality models for comparison with the CMB-apportioned ammonium nitrate and ammonium sulfate. The possibility of precursors from different source regions will be determined.

5.4.7 Annual Study Objective 7: Conceptual Model Refinement

Results of data analysis and modeling will be used to refine the conceptual models in Section 3, especially those related to nearby sources and high wind fugitive dust. Additional situations favoring high $PM_{2.5}$ may be encountered as part of these analyses.

5.4.8 Annual Study Objective 8: Simulation Methods

This objective will be addressed by the winter study. As part of the long-term annual average study, adjustments will be made to meteorological and air quality dispersion models to incorporate new concepts and parameters derived from the 100 m meteorological tower. Detailed analysis of modeling results will be made on selected episodes that represent different meteorological situations and $PM_{2.5}$ levels.